



Human Spaceflight CA Overview

SSA Operators' Workshop

November 2016

NASA/Johnson Space Center
Trajectory Operations
Bryan Corley



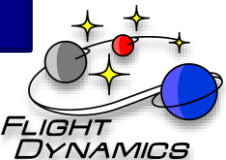
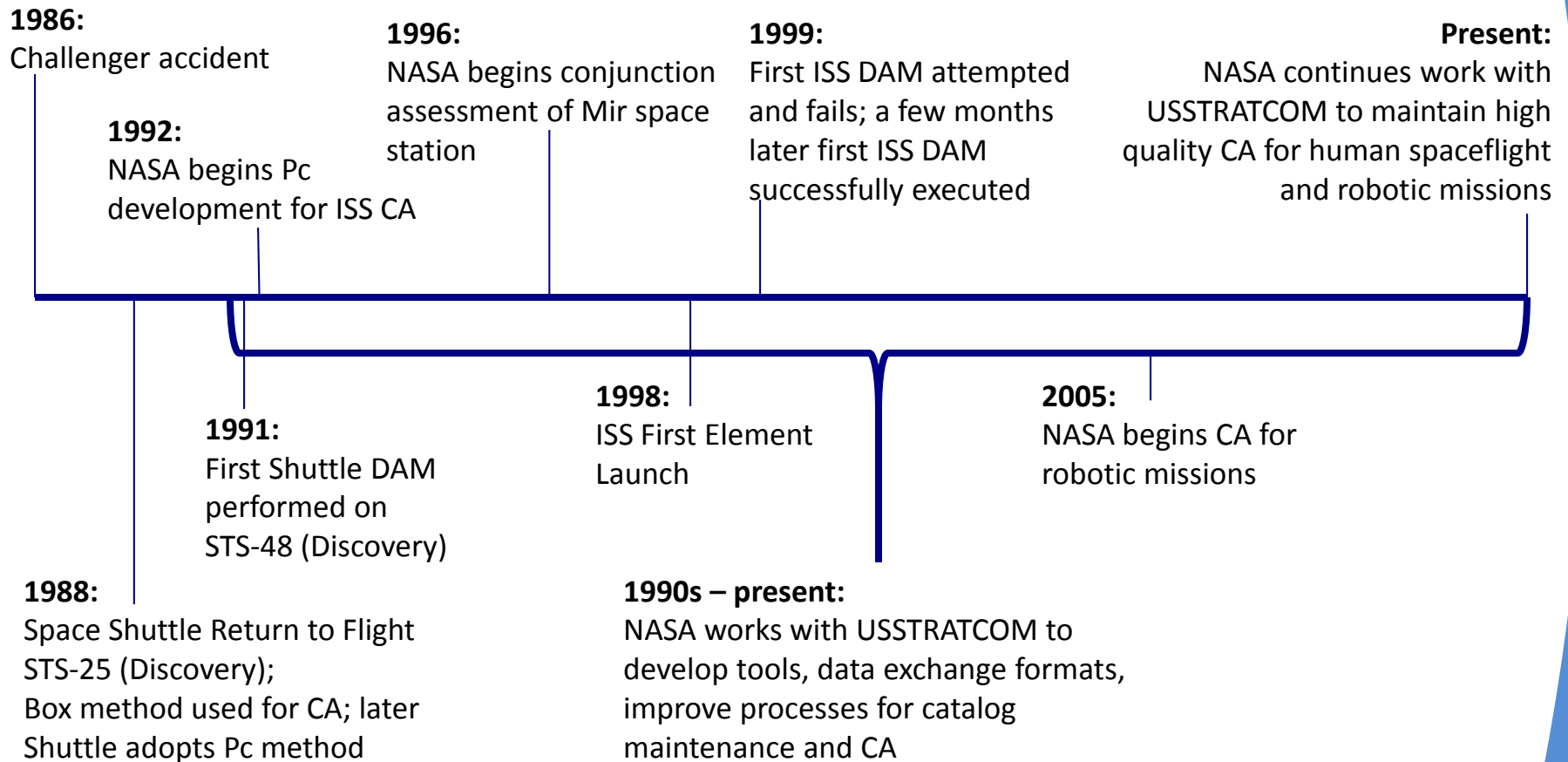
Agenda

- History
- Overview
- Metrics
- ISS Deploys
- Collaboration Efforts



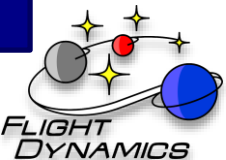
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NASA Conjunction Assessment (CA) History



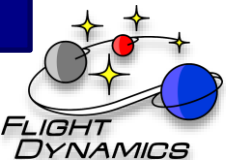
Shuttle CA Process

- Pre-Challenger - little thought given to orbital debris
- Post-Challenger - refocused attention on flight safety
- A process was created to limit risk to Space Shuttle from orbital debris
- A box, centered on the Shuttle was defined, such that predicted violations by a cataloged object could result in a maneuver
 - Maneuvers not likely
 - low catalog count, Shuttle maneuverability, short duration missions
 - No maneuvers and few notifications prior to ISS related missions



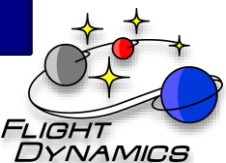
ISS CA Process Development

- Volume based risk assessment wasn't viable for long-duration ISS mission
 - Too many false alarm conjunctions would result in too many maneuvers
 - Some high risk conjunctions could be missed
- Probability based method was developed
 - Thresholds were selected as a balance of the number of expected maneuvers vs risk reduction
 - Inputs required were asset and debris state, covariance and hard-body radius
- Collaboration with USSTRATCOM led to improved predictive capabilities and covariance realism NASA used as inputs into risk assessment



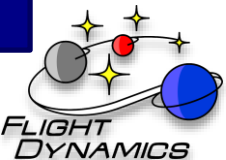
ISS CA Process: Risk Identification

- 18th Space Control Squadron (18 SPCS) screens ISS three times per day
- 18 SPCS notifies ISS Trajectory Operations and Planning Officer (TOPO) if anything is predicted to pass within ± 2 km (local vertical) x 25 km x 25 km (local horizontal) volume within the next 72 hours
- TOPO computes probability of collision (P_c)
- TOPO notifies flight control teams in Houston and Moscow of potential collision hazard risk if
 - Time of Closest Approach (TCA) ≤ 48 hours
 - Local vertical miss ≤ 0.5 km or $P_c \geq 1E-06$
 - These criteria were recently updated based on historical performance data (previous was ≤ 0.75 km without a P_c criteria)



ISS CA Process: Maneuver Decision

- TOPO refines P_c as new tracking information arrives on ISS and threat object
- TOPO monitors trends in orbit determination, covariance behavior, miss distance, and P_c
- Flight Rules govern when a DAM should be performed to minimize risk of collision
 - P_c threshold to maneuver depends on ISS activities underway or planned in near future
 - Flight Rules dictate the exceptions to perform a DAM
 - Example – inbound crewed Soyuz has launched requires higher P_c to warrant a DAM
 - Action thresholds:
 - **Black** $P_c \geq 1.0 \text{ E-}2$ (1 in 100)
 - **Red** $P_c \geq 1.0 \text{ E-}4$ (1 in 10,000)
 - **Yellow** $P_c \geq 1.0 \text{ E-}5$ (1 in 100,000)
 - **Green** $P_c < 1.0 \text{ E-}5$ (no action taken)

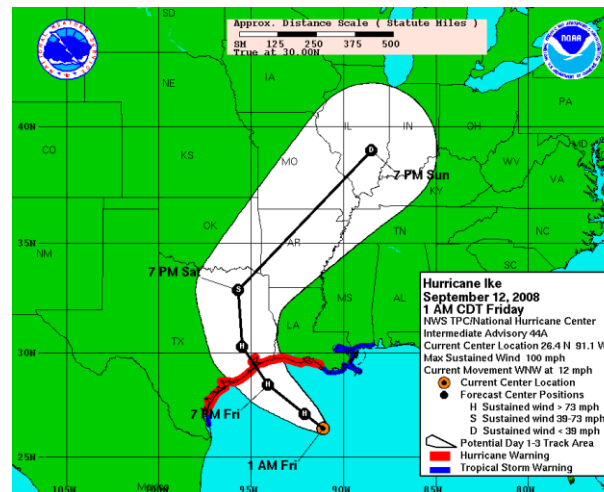


ISS CA Process

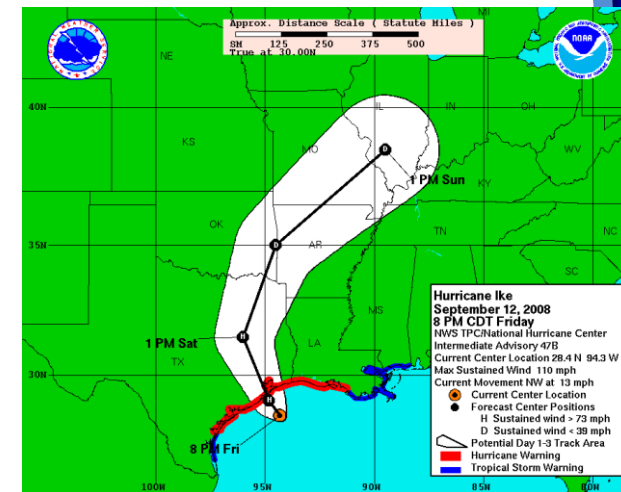
- When do you need to start Debris Avoidance Maneuver (DAM) planning?
- How long can you wait before required to make the Go/No-Go decision?
- Hurricane Ike example below (September 2008)



Landfall – 48 hours



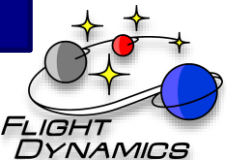
Landfall – 24 hours



Landfall – 5 hours

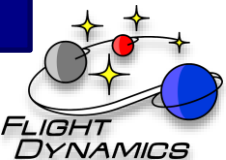
ISS CA Process: Maneuver Planning

- Prior to each ISS translation maneuver (reboost or DAM), TOPO models multiple burn options and provides data to 18 SPCS for clearing
- Options typically have a fixed ΔV required to meet constraints but have a prime ignition time ± 15 min.
- For a DAM, prime TIG is typically 2 hr 20 min from TCA
 - TIG on the N.5 rev prior to TCA maximizes vertical separation which is typically most effective to reduce risk
 - 1.5 revs prior to TCA chosen to wait as long as possible with the possibility to delay to 0.5 revs prior if ISS systems are not configured in time
- 18 SPCS clears all maneuver options against the catalog and provides results to TOPO
- TOPO iterates until a safe option is available



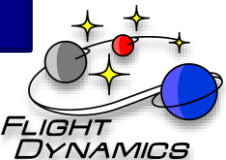
ISS CA Process: Maneuver Execution

- Legacy DAM
 - Dedicated command script (cyclogram) built by Moscow and uplinked to ISS
 - **Pros:**
 - Custom ΔV within vehicle capability – useful if eliminating near-term planned reboost
 - ISS can maneuver from any attitude to the DAM attitude LVLH YPR 0,0,0 or 180,0,0 deg
 - **Cons:**
 - Requires approximately 24-hours notice due to requirements to run on dedicated test stand. Late-notice conjunctions with high risk
 - » Crew must shelter-in-place inside Soyuz
 - Risk of debris not always known well at 24-hour decision point
 - » Maneuver can be canceled up to ignition
 - » Unused work - DAM planning which is ultimately canceled once risk decreased below action thresholds
 - » ~80% of DAM cyclograms were canceled at some point during the development due to the risk dropping below thresholds

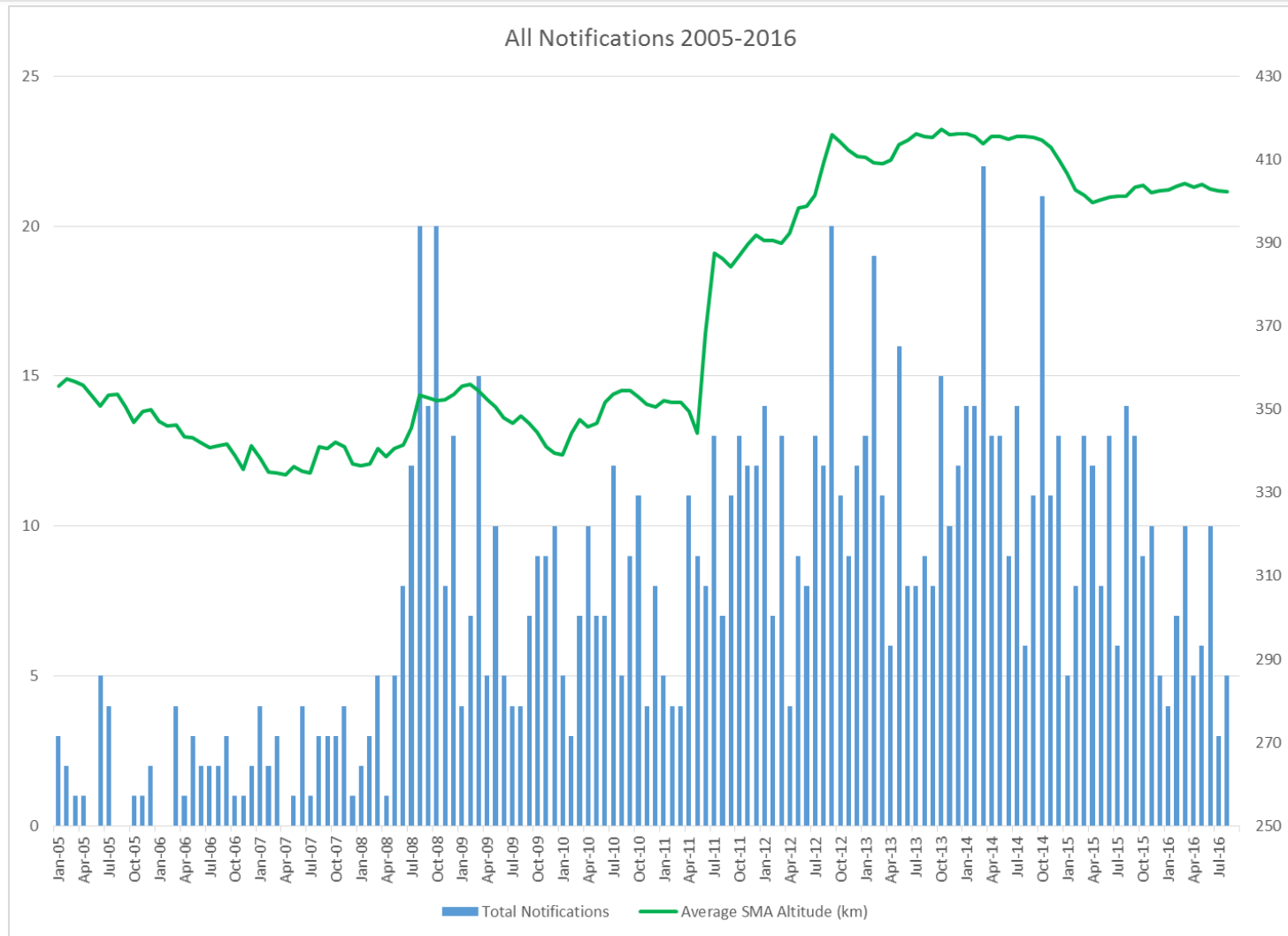


ISS CA Process: Maneuver Execution

- Pre-determined Debris Avoidance Maneuver (PDAM)
 - New operation late 2012 and primary method for ISS DAM
 - Pre-canned cyclogram executed by MCC-M or the crew 1 hour before the PDAM ignition
 - Canned ΔV options of 0.3, 0.5, 0.7 and 1.0 m/s available to choose from
- Pros
 - ISS can maneuver with as little as 3 hours notice
 - Long pole is getting ISS US systems configured for reboost (appendages in position and power down, if required)
 - Reduced unused work
 - Reduced chance of ISS crew needing to shelter-in-place for high-risk conjunctions
- Cons
 - ΔV limited to discrete options
 - ISS must be near LVLH YPR 0,0,0 or 180,0,0 attitude for PDAM cyclogram to initiate (future enhancement in work)

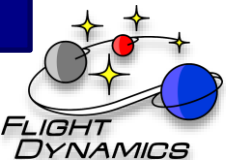


ISS Historical Conjunction Statistics



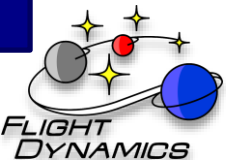
ISS Historical Conjunction Statistics

- Average annual conjunction notifications: 75 – 150
- Predicted annual DAM rate: 1.2
- 25 DAMs for ISS from 1998 (last 9/27/2015)
 - 20 Successful DAM/PDAM
 - First attempted DAM unsuccessful
 - 4 DAMs performed by Shuttle while docked to ISS
- 4 ISS crew shelter-in-place (last 7/16/2015)



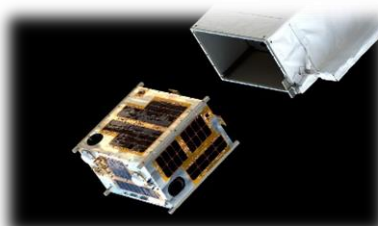
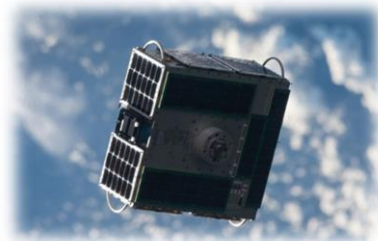
Deploys from ISS

- ISS is equipped with 5 deployers
 - JEM Small Satellite Orbital Deployer (J-SSOD) (1U – 3U cubesats)
 - JEM Small Satellite Orbital Deployer M1 (J-SSOD M1)
 - JEM Small Satellite Orbital Deployer UG (J-SSOD UG) currently in development
 - NanoRacks CubeSat Deployer (NRCSD)
 - Space Station Integrated Kinetic Launcher for Orbital Payload Systems (Cyclops)
 - NanoRacks Kaber
 - Jettisons also possible during US or Russian EVA's
- External NRCSD (eNRCSD) attached to Cygnus Spacecraft
 - Capable of deploying 36U worth of satellites
- Over 120 objects deployed/jettisoned since 2013



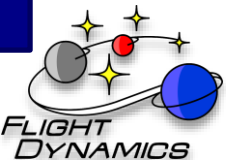
2016 Recent Deploys

- CYCLOPS Lonestar (01/29)
 - Lonestar (& Subdeployable Bevo)
- Russian Flash Drive (02/03)
- JSSOD M-1 (04/27)
 - PHL-MicroSat (DIWATA 1)
- NRCSD-7 (05/16-05/18)
 - 8 Doves, 4 LEMURS, STMSat-1, NODEs 1 & 2, MinXSS, and CADRE
- NRCSD-8 (05/30-06/02)
 - 16 Doves
- eNRCSD-1 (06/21)
 - LEMUR 3U satellites deployed 15 km below and ISS
 - Only 4/5 successful due to deployer door hangup
- NRCSD-9 (09/14-15)
 - 8 Doves



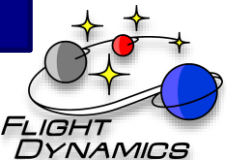
Deploy Collaboration

- TOPO is responsible for the trajectory safety assessment for deploys from ISS
- Global Precipitation Measurement Mission (GPM) is a NASA/JAXA mission launched into similar orbit as ISS in 2014
 - Follow-up mission to Tropical Rainfall Measuring Mission (TRMM)
- ISS cubesat deployments are a potential risk to GPM until they are tracked by 18 SPCS at which time established CA processes take effect
- ISS/TRMM had an MOA with data sharing agreements for trajectory information including maneuvers to assure safety of both vehicles
- ISS/GPM adapted the MOA for our respective operations and expanded it to include a risk assessment deploys could impose on GPM. Consideration will be given to delay deploys until a safe window opens up with respect to GPM



Other Collaboration

- ISS has collaborated with other missions to exchange information and assure safety
- Launch operations
 - Most DoD or NASA launches that leave payload or upper stages in orbits that cross ISS provide data to perform an additional risk assessment between what is typically required by the ranges
 - Typical LCOLA screens for 3 hours after powered flight. Additional analysis sometimes performed to assure ISS is safe for 36-hours which is more realistic for how quickly a risk is assured to be identified and mitigated in necessary
 - LISA pathfinder
- Deorbit operations such as Compton Gamma Ray Observatory (CGRO)
- Initial communication other commercial providers such as Thumbsat and Planet. Regulatory agencies are requesting ISS input on risk future missions could impose
- Collaboration and transparency is a key to safe operations for all





Questions?

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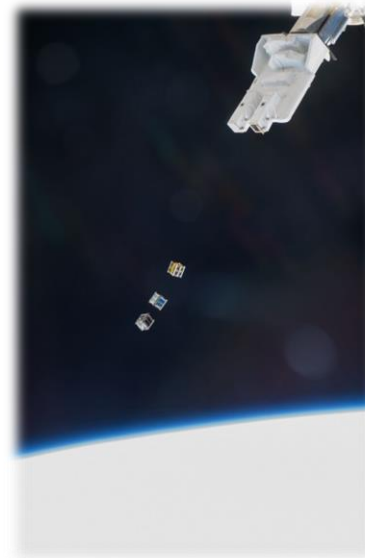


Backup Slides



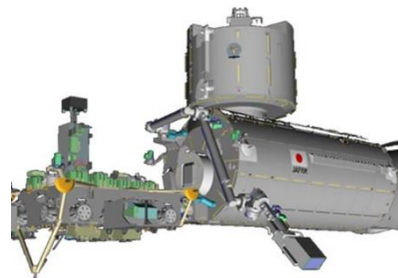
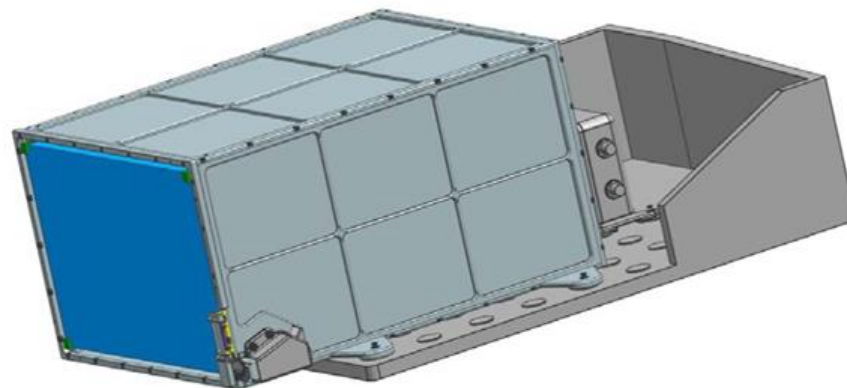
J-SSOD

The JEM Small Satellite Orbital Deployer (J-SSOD) consists of two (2) 3 U deployers. The J-SSOD has a deploy capacity of 6U and two (2) deploy events can be completed in 1-2 days. The figures show the J-SSOD mechanism and the J-SSOD on orbit.

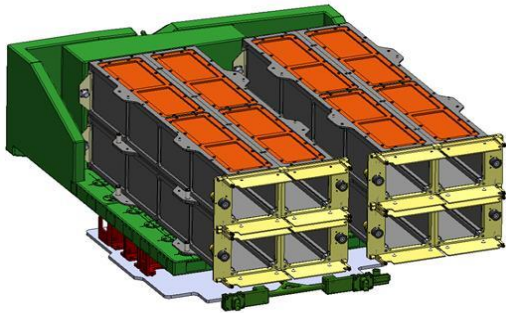


J-SSOD M1

The JEM Small Satellite Orbital Deployer (J-SSOD) M1 is designed to deploy a larger volume small satellite than the J-SSOD deployer. The figures show the deploy mechanism and the planned deployment position on orbit.



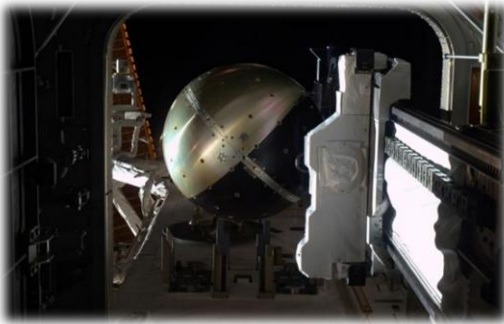
NRCSD



The NanoRacks CubeSat Deployer (NRCSD) consists of eight (8) 6 U deployers. The NRCSD has a deploy capacity of 48U and eight (8) deploy events can be completed in 4-5 days. The figures show the NRCSD mechanism and NRCSD on orbit. Empty deployers return on Dragon for reuse.



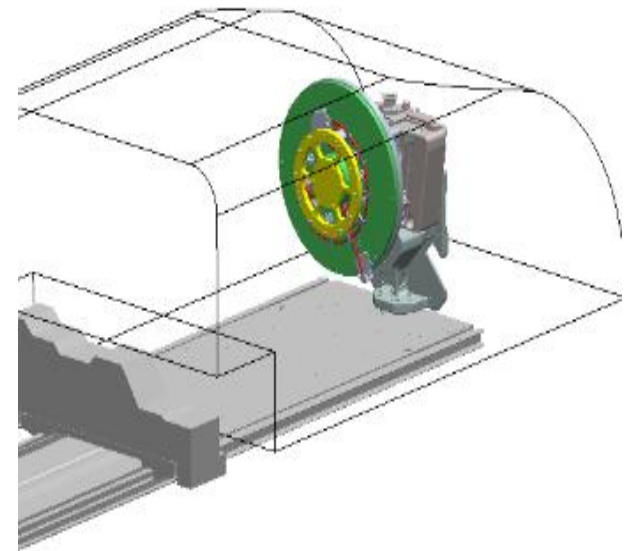
CYCLOPS



The Space Station Integrated Kinetic Launcher for Orbital Payload Systems (Cyclops, originally named SSIKLOPS) was developed by JSC Engineering Directorate to deploy single large payloads up to 100 kg that maximize use of the JEM-AL volume. The Cyclops is moved to deploy position by the JEM-RMS/Small Fine Arm (SFA) or SSRMS/SPDM and is stored on ISS for reuse. The figures show the Cyclops deployed and ready to deploy SpinSat and Cyclops awaiting to be moved to a deploy position.

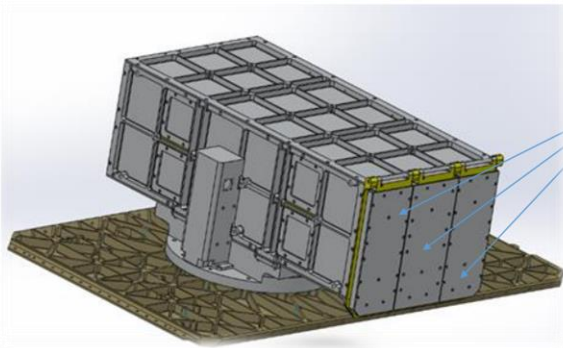
Kaber

- The NanoRacks Kaber Microsatellite Deployer System is an on-orbit small satellite deployment system that will be used to deploy satellites from the ISS. Its deploy capabilities are similar to Cyclops, but it is designed to deploy payloads with the Special Purpose Dexterous Manipulator (SPDM) utilizing the Japanese Experiment Module (JEM) airlock and slide table.
- Payloads that are to be deployed by Kaber will be integrated with the deployer on-board the ISS by ISS crew members. The deployer/payload is then transferred out of the ISS via the JEM airlock. Once outside, Kaber will be retrieved by the Space Station Remote Manipulator System (SSRMS) / Special Purpose Dexterous Manipulator (SPDM) and moved to the appropriate deploy location. Once in the deploy location and orientation the payload is deployed.



eNRCSD

- Externally mounted 2 x 3 configuration with 6U of capability per chamber (x6 chambers -> 36U of capability)
- OA5 will be performing a deployment of 4 LEMUR satellites above ISS from a 45 km co-ellptic orbit



JSSOD UG

- JAXA is developing the J-SSOD - UG which will have the ability to deploy 12U of cubesats at one mission.
- This is essentially the same design as the original JSSOD, with the addition of two more deployers sitting atop the location of the originals and the necessary additional electronics

